EAST Search History

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L2	2	("6788268").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2007/03/14 06:31
L3	2	("6624784").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2007/03/14 06:31
L5	56	(evaluation adj function) and (antenna near2 array)	US-PGPUB; USPAT; USOCR	OR	ON	2007/03/14 06:35
L9	3	(plurality near2 antenna) and (adaptive adj antenna adj array) and (weight$4) and (reactance)	US-PGPUB; USPAT; USOCR	OR	ON	2007/03/14 07:04
L10	108	(plurality near2 antenna) and (antenna adj array) and (weight$4) and (reactance)	US-PGPUB; USPAT; USOCR	OR	ON	2007/03/14 07:52
L11	2	("6989721").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2007/03/14 07:54
L12	2	("6677898").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2007/03/14 08:18
L13	2	("6496144").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2007/03/14 08:18

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L15	2	("6327314").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2007/03/14 08:22
L17	42	(adaptive adj antenna) and (parasitic adj antenna)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2007/03/14 11:34
L20	21	(adaptive near2 antenna near2 antenna) and ((A?D or (digital near2 convert$4)) with over$1sampl$4)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2007/03/14 15:55
L21	12	(transfer adj function) with (impulse adj response) with multipath	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2007/03/14 15:55
S1	2	("20040192394").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2007/03/13 12:51
S2	2	("4074358").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2007/03/13 11:46
S4	2	("6407719").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2007/03/13 12:51

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S5	2	("6677898").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2007/03/13 12:53
S6	2	("7057573").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2007/03/13 12:53
S11	4	("7106270").PN.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2007/03/13 13:37
S12	1	espar and (perturb$4 near3 (no$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2007/03/13 14:29
S13	5	"6882849"	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2007/03/13 14:15
S14	72	antenna and (perturb$4 near3 (no$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2007/03/13 14:35
S15	18	reactance and (perturb$4 near3 (no$1))	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2007/03/13 14:46

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S16	105	(espar or (adaptive adj antenna adj array)) and FFT	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2007/03/13 14:47
S17	91	(espar or (adaptive adj antenna adj array)) and FFT and control$4	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2007/03/13 14:47

Wireless
Communication

JPL's Wireless Communication Reference Website

Chapter: Wireless Channels
Section: Multipath Fading

Delay Spread

Because of multipath reflections, the channel impulse response of a wireless channel looks likes a series of pulses. In practice the number of pulses that can be distinguished is very large, and depends on the time resolution of the communication or measurement system.

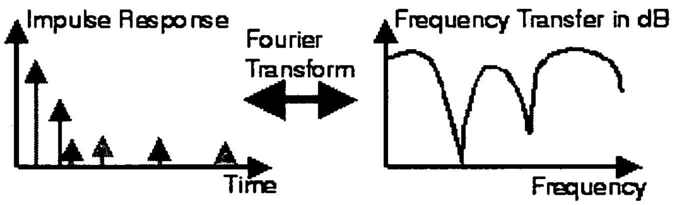
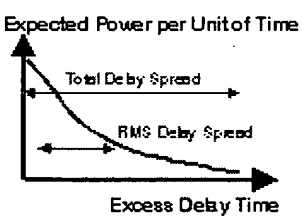


Figure: Example of impulse response and frequency transfer function of a multipath channel.

In system evaluations, we typically prefer to address a class of channels with properties that are likely to be encountered, rather than one specific impulse response. Therefor we define the (local-mean) average power which is received with an excess delay that falls within the interval $(T, T + dt)$. Such characterization for all T gives the "delay profile" of the channel.

The delay profile determines the frequency dispersion, that is, the extent to which the channel fading at two different frequencies f_1 and f_2 is correlated.

Some definitions



- The maximum delay time spread is the total time interval during which reflections with significant energy arrive.
- The r.m.s. delay spread T_{RMS} is the standard deviation (or root-mean-square) value of the delay of reflections, weighted proportional to the energy in the reflected waves.

For a digital signal with high bit rate, this dispersion is experienced as frequency selective fading and intersymbol interference (ISI). No serious ISI is likely to occur if the symbol duration is longer than, say, ten times the r.m.s. delay spread.

Typical Values

In macro-cellular mobile radio, delay spreads are mostly in the range from T_{RMS} is about 100 nsec to 10 microsec. A typical delay spread of 0.25 microsec corresponds to a coherence bandwidth of about 640 kHz. Measurements made in the US, indicated that delay spreads are usually less than 0.2 microsec in open areas, about 0.5 microsec in suburban areas, and about 3 micros in urban areas. Measurements in The Netherlands showed that delay spreads are relatively large in European-style suburban areas, but rarely exceed 2 microsec. However, large distant buildings such as apartment flats occasionally cause reflections with excess delays in the order of 25 microsec.

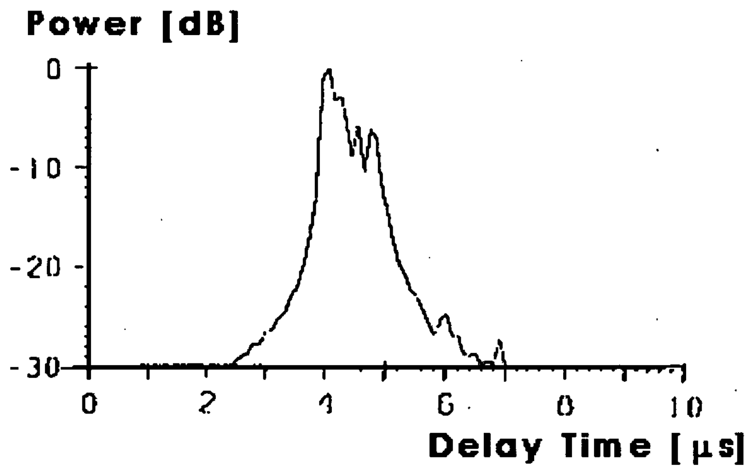


Figure: Measured Delay profile in a German urban environment at 1800 MHz

Delay Spread = 1.2 μsec; coherence BW = 1.3 MHz
Source: Research group of Prof. Paul Walter Baier, U. of Kaiserslautern, Germany.
See also: corresponding scatter plot.

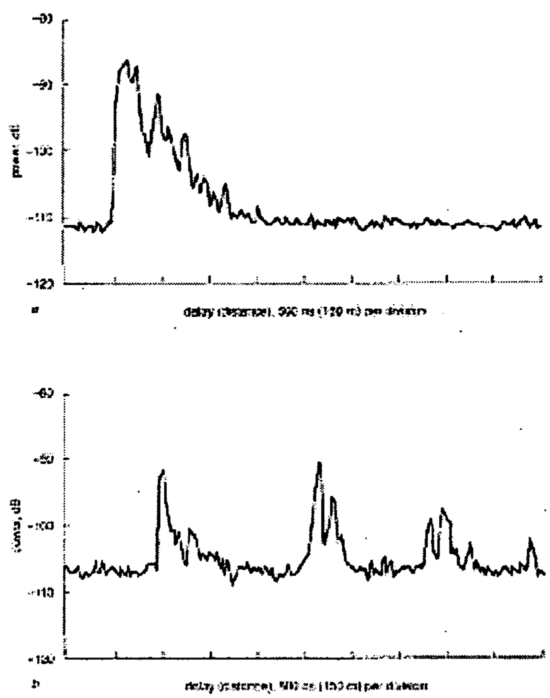


Figure: Example of delay profile.

MP2 audio: Measured channel data in Edinburgh.

Source: Research group of Prof. Peter Grant, U. of Edinbourough. See also: discussion of channel modeling to study CDMA array processing. Playlist leading you through the topic of array processing and adaptive antennas for CDMA. It includes a discussion of the channel model.

The Indoor Channel

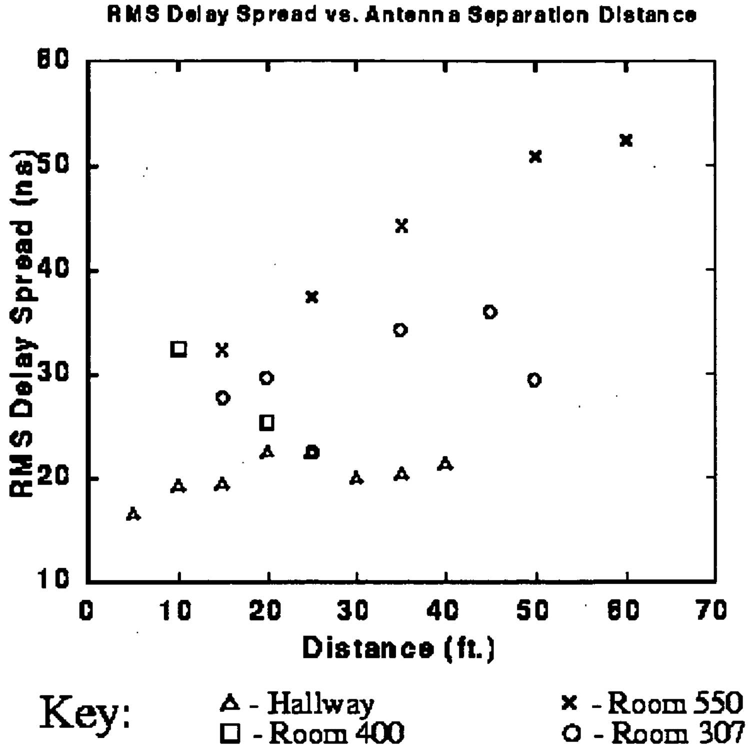


FIGURE: R.M.S. Delay Spread vs. propagation distance in the U.C. Berkeley, Cory Hall Building.
Source: John Davis and Jean-Paul Linnartz

In indoor and micro-cellular channels, the delay spread is usually smaller, and rarely exceed a few hundred nanoseconds. Seidel and Rappaport reported delay spreads in four European cities of less than 8 microsec in macro-cellular channels, less than 2 microsec in micro-cellular channels, and between 50 and 300 ns in pico-cellular channels.

Delay Profile

The delay profile is the expected power per unit of time received with a certain excess delay. It is obtained by averaging a large set of impulse responses.

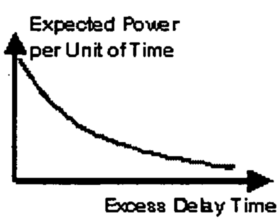


Figure: Typical delay profile: Exponential

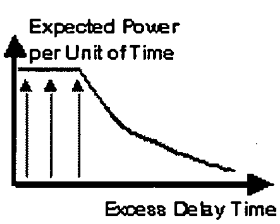


Figure: Typical indoor delay profile:

In an indoor environment, early reflections often arrive with almost identical power. This gives a fairly

flat profile up to some point, and a tail of weaker reflections with larger excess delay.

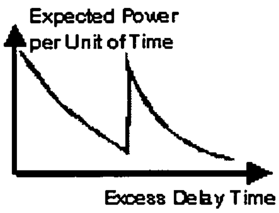


Figure: Typical "bad urban" delay profile

Besides the normal reflections from nearby obstacles (which cause reflection with a short excess delay), remote high-rise buildings cause strong reflections with large excess delay. The combined effects often result in multiple clusters of reflections.

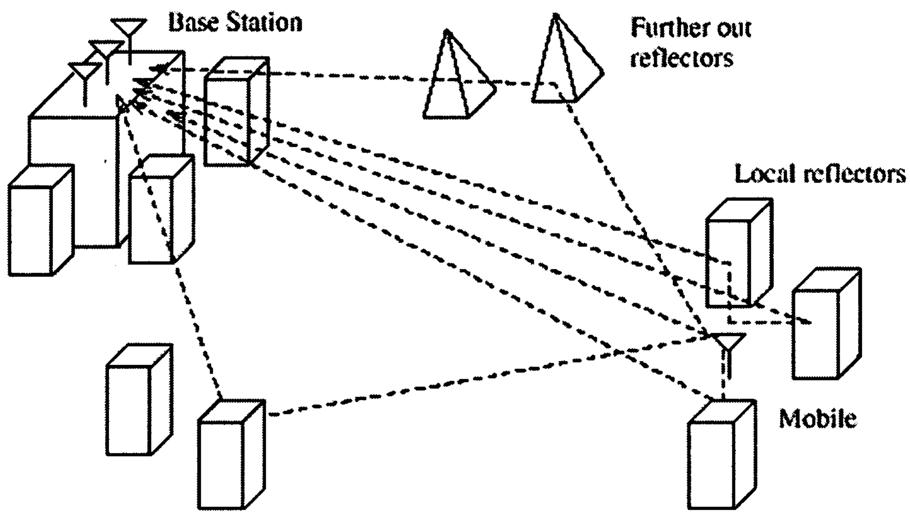


Figure: Illustration of reflections of various kinds.
Source: Peter Grant, U. of Edinbourough.

From the delay profile, one can compute the correlation of the fading at different carrier frequencies.

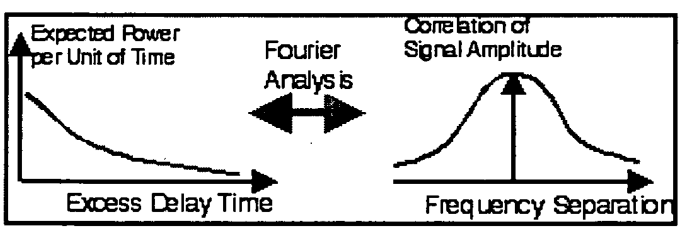


Figure Auto-Covariance of the received amplitude of two carriers transmitted with certain frequency offset.

COST 207 Reference Models

The COST 207 project proposed reference models using the exponential profile with one or two decaying peaks. The model with two peak is similar to the above bad urban model.

Urban, nonhilly:	$\exp(-\tau/1\mu s)$	
Rural, nonhilly:	$\exp(-9.2\ \tau/1\mu s)$	
Bad urban, hilly:	$\exp(-\tau/1\mu s)$	for $0 < \tau < 5\mu s$

	$0.5 \exp(5-\tau/1\mu s)$	for $5 < \tau < 10\mu s$
Hilly:	$\exp(-3.5\ \tau/1\mu s)$ $0.1 \exp(15-\tau/1\mu s)$	for $0 < \tau < 2\mu s$ for $15 < \tau < 20\mu s$

The above expressions only represent the behavior of the profile curve. A correction factor is needed to ensure that the integral over all τ equals unity, or to represent the total local-mean power.

Resolvable Paths

A wideband signal with symbol duration T_c (or a direct sequence (DS)-CDMA signal with chip time T_c), can "resolve" the time dispersion of the channel with an accuracy of about T_c. For DS-CDMA, the number of resolvable paths is

$$N = \mathrm{round}\left(\frac{T_{Delay}}{T_{chip}}\right) + 1$$

where round(x) is the largest integer value smaller than x and T_{Delay} is total length of the delay profile. A DS-CDMA Rake receiver can exploit N-fold path diversity.

How do systems handle delay spreads?

System	Countermeasure
Analog	• Narrowband transmission
GSM	• Adaptive channel equalization • Channel estimation training sequence
DECT	• Use the handset only in small cells with small delay spreads • Diversity and channel selection can help a little bit (pick a channel where late reflections are in a fade)
IS95 Cellular CDMA	• Rake receiver separately recovers signals over paths with excessive delays. CDMA array processing can further improve performance, because it also exploits angle spreads.
Digital Audio Broadcasting	• OFDM multi-carrier modulation: The radio channel is split into many narrowband (ISI-free) subchannels

Measuring the delay spread

Often propagation parameters are measured in frequency domain. Klaus Witrisal discusses how the delay spread can be estimated directly from a frequency transfer function.

ToC CONTENTS BACK TO BASICS SEE ALSO